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The modeling and forecasting of extreme events in electricity spot markets

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ABSTRACT

Primary concerns for traders since the deregulation of electricity markets include both the selection of optimal trading limits and risk quantification. These concerns have come about as a consequence of the unique stylized attributes of electricity spot prices, such as the clustering of extremes, heavy tails and common spikes. We propose self-exciting marked point process models, which can be defined in terms of either durations or intensities, and which can capture these stylized facts. This approach consists of modeling the times between extreme events and the sizes of exceedances which surpass a high threshold. Empirical results for four major electricity spot markets in Australia show evidence of dependence between the occurrence times of extreme returns. This finding is directly related to the future behavior of the stochastic intensity process for price spikes. In addition, the proposed approach also provides more accurate one-day-ahead value at risk (VaR) forecasting in electricity markets than standard stochastic volatility models.

1. Introduction

Electricity spot markets are a challenging research area, due to the unique characteristics of energy markets, such as the fact that any rise in demand or drop in production needs to be addressed by the trader, often with a high marginal cost. This highly inelastic demand is often responsible for price jumps to extreme levels, a characteristic known in the literature as a "spike". For instance, spot price spikes in Australia's National Electricity Market (NEM) can peak at levels above AUD$1000/MWh, while it is also common to observe daily prices reaching levels of between AUD$100/MWh and AUD$1000/MWh, either of which could be described as an extremely high price (Becker & Hurn, 2007; Christensen, Hurn, & Lindsay, 2012; Clements, Fuller, & Hurn, 2013). Compared to other financial markets, risk management in the electricity market is a relatively new area, having been introduced after the restructuring of the Australian electricity industry in the late 1990s. Most of the approaches to forecasting electricity spot prices focus on predicting the series' next prices (Chan, Gray, & van Campen, 2008; Conejo, Contreras, Espinola, & Plazas, 2005; Karakatsani & Bunn, 2008; Soares & Medeiros, 2008), mainly because prices in the spot market are highly volatile, and the spot price can spike to several hundred times the average price within a short period.

An assumption made in most of these approaches is the memory-free nature of the spikes' behavior. However, recent research on electricity prices has found evidence that the time between spikes has a significant impact on the likelihood of future occurrences (Christensen, Hurn, & Lindsay, 2009; Christensen et al., 2012; Clements et al., 2013). Thus, the aim of this paper is to determine whether the times between past extreme events in elec-

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tricity spot price returns contain some information which can be used to forecast the future behavior of these returns.

This paper's contribution to the existing state of knowledge in the modeling of extreme movements in electricity prices is twofold. First, we introduce a framework that captures the short-term behavior of extreme events in electricity spot price returns based on the most recent extreme event times and some exogenous covariates, which are believed to influence the behavior of these events. In particular, we include three components as covariates. The first covariate is the electricity load, which is characterized by varying behaviors due to customer portfolios, as a result of the liberalization of the Australian electricity market. The second covariate is temperature, which can affect electricity demand and production. For example, in a dry year, if the main source is hydropower, it will not be possible to produce the normal amount of electricity. It would therefore be necessary to look for alternatives, which may result in more expensive production methods (Golombek, Kittelsen, & Haddeland, 2012). The third covariate is the exceedance sizes of these spike price returns, which, according to other stock market applications, could have a direct relationship with the time between occurrences of these events.[1]

We propose a self-exciting marked point process (SEMPP) framework, which can be defined in terms of either duration-based or intensity-based approaches. The duration-based approach corresponds to an autoregressive conditional duration peaks over threshold (ACD-POT) model (Herrera & Schipp, 2013), while the intensity-based approach corresponds to a Hawkes model for the exceedance times combined with a peaks over threshold model (Hawkes-POT) for the marks (Chavez-Demoulin, Davison, & McNeil, 2005; Chavez-Demoulin & McGill, 2012). These models allow us to concentrate only on these extreme events, rather than considering the entire dataset, and thus provide risk measures through which traders can select optimal trading limits.

The authors of this paper also apply these new models to four major electricity markets in Australia: New South Wales, Queensland, South Australia and Victoria. The models are compared using a competing approach, the AR-APARCH-EVT, giving better results for the one-day-ahead value at risk (VaR) forecast out-of-sample.

The results obtained by this investigation indicate a significant improvement in the forecasting of different risk measures, the overall accuracy, and a backtesting analysis. The most interesting result in this paper is the significant evidence of dependence between inter-exceedance times (the time between extreme events) in the markets, which are directly related to the intensity of the stochastic process of price spikes.

The rest of this paper is organized as follows: Section 2 presents a literature review dealing with electricity spot prices. Section 3 describes the proposed approach, introducing the ACD-POT and Hawkes-POT models and their parameterizations. In Section 4, the Australian electricity markets are analyzed using the proposed methodology. Section 5 presents the conclusions.

[1] Chavez-Demoulin and McGill (2012) showed that for high frequency stock market data, the impact of large losses on the intensity of the process is driven by the amplitude of the losses, and decreases in relation to the time between extreme events.

2. Literature review

The daily spot prices in electricity markets exhibit interesting stylized facts at both the intra-day and daily levels. These stylized facts include mean reverting behaviour, high volatility, price spikes and jump clustering (Karakatsani & Bunn, 2008; Klüppelberg, Meyer-Brandis, & Schmidt, 2010). Price spikes present a common problem in electricity markets, and therefore, various approaches have been proposed in the literature for explaining these. Three main frameworks are highlighted below.

The first considers modeling the spot price, or return trajectory, by means of classical time series. For instance, Conejo et al. (2005) present a review of autoregressive moving average (ARMA) and autoregressive moving average with exogenous inputs (ARMAX) models, while Higgs (2009) considers a generalized autoregressive conditional heteroskedasticity (GARCH) process. Other approaches address the modeling of price spikes through Markov switching models (Becker & Hurn, 2007; Kosater & Mosler, 2006) or Markov diffusion processes (Higgs & Worthington, 2008; Meyer-Brandis & Tankov, 2008).

The second set of approaches focuses on the estimation and forecasting of risk measures for both short- and long-trading positions in electricity markets. In particular, Vehviläinen and Keppo (2004), based on both stochastic consumption and prices, propose hedging strategies in the Nordic electricity market using VaR as a risk measure. Deng and Jiang (2005) introduce a Levy process-driven Ornstein–Uhlenbeck stochastic model for electricity prices, and propose VaR and expected shortfall (ES) as important measures of portfolio diversification. Byström (2005) and Chan and Gray (2006) compute VaR by means of extreme value theory (EVT) and adjust the volatility in the time series with a GARCH model.

The third alternative focuses on forecasting the likelihood of extreme price events, rather than the trajectory of the price. In particular, Christensen et al. (2009) introduce a Poisson autoregressive framework and Christensen et al. (2012) present an autoregressive conditional hazard (ACH) model for forecasting extreme price events. Similarly, Clements et al. (2013) propose a semi-parametric nonlinear variant of the ACH model for forecasting spikes. The forecast results obtained using these approaches, based on discrete point processes, seem to be more accurate than those of previous approaches. In particular, this semi-parametric nonlinear variant produces better results out-of-sample, which is attributable to the ability of the approach to capture the inherent nonlinearity in the spike process.

In the same line, the basic framework in our research is based on continuous SEMPP. In particular, we introduce some variants of the ACD-POT (Herrera & Schipp, 2013) and Hawkes-POT (Chavez-Demoulin & McGill, 2012) approaches, which model the dependence between the inter-exceedance times. Employing this method, we concentrate on forecasting the VaR rather than on predicting spot prices. Using this model, traders are able to plan strategies for their bidding on the spot market for upcoming periods.